

MATHEMATICAL MODELS IN CAP88-PC

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June 1997

The purpose of this document is to present the mathematical models and equations used in CAP88-PC for environmental transport and estimation of dose and risk. In order to facilitate comparison of the programs with the theoretical model by interested users, the actual variable names used in the CAP88-PC FORTRAN code have been included in brackets, where applicable, following the explanation of the mathematical symbols used in the formulas.

1. ENVIRONMENTAL TRANSPORT

CAP88-PC incorporates a modified version of the AIRDOS-EPA (Mo79) program to calculate environmental transport. Relevant portions of this document are reproduced here, as referenced.

1.1 Plume Rise

CAP88-PC calculates plume rise in the subroutine CONCEN using either Rupp's equation (Ru48) for momentum dominated plume rise, or Briggs' equations (Br69) for hot buoyant plumes (Mo79). CAP88-PC also accepts user-supplied values for plume rise for each Pasquill stability class. The plume rise, Δh , is added to the actual physical stack height, h [PH], to determine the effective stack height, H . The plume centerline is shifted from the physical height, h , to H as it moves downwind. The plume centerline remains at H unless gravitational settling of particulates produces a downward tilt, or until meteorological conditions change.

Rupp's equation for momentum dominated plumes is:

$$\Delta h = \frac{1.5 \text{ vd}}{\mu} \quad (\text{Equation 1})$$

where:

$$\begin{aligned} \Delta h &= \text{plume rise [PR]} \\ V &= \text{effluent stack gas velocity (m/sec) [VEL]} \\ d &= \text{inside stack diameter (m) [DIA]} \\ \mu &= \text{wind velocity (m/sec) [U]} \end{aligned}$$

CAP88-PC models Briggs' buoyant plume rise for stability categories A,B, C, and D with:

$$\Delta h = \frac{1.6 F^{1/3} x^{2/3}}{\mu} \quad \text{(Equation 2)}$$

where:

Δh	=	plume rise [PR]
F	=	$3.7 \times 10^{-5} Q_H$
Q_H	=	heat emission from stack gases (cal/sec) [QH]
x	=	downwind distance (m)
μ	=	wind speed (m/sec) [U]

This equation is valid until the downwind distance is approximately ten times the stack height, 10h, where the plume levels off. For downwind distances greater than 10h, the equation used is:

$$\Delta h = \frac{1.6 F^{1/3} (10h)^{2/3}}{\mu} \quad \text{(Equation 3)}$$

Equation (2) is also used to a distance of $X = 2.4 \mu S^{-1/2}$ for stable categories E, F, and G, beyond which the plume is assumed to level off. For higher values of x, the stability parameter, S, is used in the equation:

$$\Delta h = 2.9(F/\mu S)^{1/3} \quad \text{(Equation 4)}$$

in which:

S	=	$(g/T_a) (\partial T_a / \partial z + \Gamma)$	(Equation 5)
g	=	gravitational acceleration (m/sec ²)	
T	=	air temperature (°K) [TEMPERATURE]	
$\partial T_a / \partial z$	=	vertical temperature gradient (°K/m) [TG]	
z	=	vertical distance above stack (m)	
Γ	=	adiabatic lapse rate of atmosphere (0.0098° K/m)	

The value of the vertical temperature gradient, $\partial T_a / \partial z$, is positive for stable categories. In CAP88-PC, $\partial T_a / \partial z$ values are:

- 7.280E-02 ° K/m for Pasquill category E
- 1.090E-01 ° K/m for Pasquill category F
- 1.455E-01 ° K/m for Pasquill category G

The true-average wind speed for each Pasquill stability category is used in CAP88-PC to estimate plume rise, as it is greater than the reciprocal-averaged wind speed and produces a smaller, more conservative plume rise. This procedure does not risk underestimating the significant contribution

of relatively calm periods to downwind nuclide concentrations which could result from direct use of a plume rise calculated for each separate wind-speed category. This procedure avoids calculating an infinite plume rise when wind speed is zero (during calms), since both momentum and buoyancy plume rise equations contain wind speed in the denominator (Mo79).

CAP88-PC also accepts user-supplied plume rise values, for situations where actual measurements are available or the supplied equations are not appropriate. For example, plume rises of zero may be used to model local turbulence created by building wakes.

1.2 Plume Dispersion

Plume dispersion is modeled in the subroutine CONCEN with the Gaussian plume equation of Pasquill (Pa61, Mo79), as modified by Gifford:

$$\chi = \frac{Q}{2 \pi \sigma_y \sigma_z \mu} \exp[-1/2(y/\sigma_y)^2] \{ \exp[-1/2((z-H)/\sigma_z)^2] + \exp[-1/2((z+H)/\sigma_z)^2] \}$$

(Equation 6)

where:

χ	=	concentration in air (chi) at x meters downwind, y meters crosswind, and z meters above ground (Ci/m ³) [ACON]
Q	=	Release rate from stack (Ci/sec) [REL]
μ	=	wind speed (m/sec) [U]
σ_y	=	horizontal dispersion coefficient (m)
σ_z	=	vertical dispersion coefficient (m)
H	=	effective stack height (m)
y	=	crosswind distance (m)
z	=	vertical distance (m)

The downwind distance x comes into Equation (6) through σ_y and σ_z , which are functions of x as well as the Pasquill atmospheric stability category applicable during emission from the stack. CAP88-PC converts χ in Equation (6) and other plume dispersion equations from units of curies per cubic meter to units of picocuries per cubic centimeter.

Annual-average meteorological data sets usually include frequencies for several wind-speed categories for each wind direction and Pasquill atmospheric stability category. CAP88-PC uses reciprocal-averaged wind speeds in the atmospheric dispersion equations, which permit a single calculation for each wind-speed category.

Equation (6) is applied to ground-level concentrations in air at the plume centerline by setting y and z to zero, which results in:

$$\chi = \frac{Q}{\Pi \sigma_y \sigma_z \mu} \exp[-1/2(H/\sigma_z)^2] \quad (\text{Equation 7})$$

The average ground-level concentration in air over a sector of 22.5° can be approximated by the expression:

$$\chi_{\text{ave}} = f\chi \quad (\text{Equation 8})$$

where f is the integral of the exponential expression:

$$\exp[-1/2(y/\sigma_y)^2]$$

in Equation (6) from a value of y equals zero to infinity divided by y_s , the value of y at the edge of the 22.5° sector, which is the value of the downwind distance, x, multiplied by the tangent of half the sector angle. The expression is:

$$f = \frac{\int_0^{\infty} \exp[-(0.5/\sigma_y^2)y^2] dy}{y_s} \quad (\text{Equation 9})$$

The definite integral in the numerator of Equation (9) is evaluated as

$$\sigma_y (\pi/2)^{1/2} \quad (\text{Equation 10})$$

Since $y_s = x \tan (11.25^\circ)$,

$$f = \frac{6.300836\sigma_y}{x} \quad (\text{Equation 11})$$

The equation for sector-averaged ground level concentration in air is therefore:

$$\chi = \frac{Q}{0.15871\pi x \sigma_z \mu} \exp[-1/2(H/\sigma_z)^2] \quad (\text{Equation 12})$$

This method of sector-averaging compresses the plume within the bounds of each of the sixteen 22.5° sectors for unstable Pasquill atmospheric stability categories in which horizontal dispersion is great enough to extend significantly beyond the sector edges. It is not a precise method, however, because the integration over the y-axis, which is perpendicular to the downwind direction, x, involves increasing values for x as y is increased from zero to infinity.

An average lid for the assessment area is provided as part of the input data. The lid is assumed not to affect the plume until x becomes equal to $2x_L$, where x_L is the value of x for which $\sigma_z = 0.47$ times the height of the lid (Tu69). For values of x greater than $2x_L$, vertical dispersion is restricted and radionuclide concentration in air is assumed to be uniform from ground to lid.

The average concentration between ground and lid, which is the ground-level concentration in air for values of x greater than $2x_L$, may be expressed by:

$$X_{ave} = \frac{\int_0^{\infty} X dz}{L} \quad \text{(Equation 13)}$$

where X is taken from Equation (6) and L is lid height. The value of H in Equation (6) may be set at zero since X_{ave} is not a function of the effective stack height.

The resulting simplified expression may be evaluated for constant x and y values (σ_y and σ_z held constant) by using a definite integral similar to that in Equation (10):

$$X_{ave} = \frac{\int_0^{\infty} \frac{Q}{\sigma_y \sigma_z \mu} \exp(-z^2/2\sigma_z^2) \exp(-y^2/2\sigma_y^2) dz}{L} \quad \text{(Equation 14)}$$

The result is:

$$X_{ave} = \frac{Q}{2.5066 \sigma_y L \mu} \exp(-y^2/2\sigma_y^2) \quad \text{(Equation 15)}$$

One obtains the sector-averaged concentration at ground level by replacing the exponential expression containing y by f in Equation (11):

$$X_{ave} = \frac{Q}{0.397825 x L \mu} \quad \text{(Equation 16)}$$

It should be noted at this point that for values of the downwind distance greater than $2x_L$ dispersion, as expressed in Equation (16), no longer can be said to be represented by the Pasquill equation. The model is simply a uniform distribution with a rectangle of dimensions LID and $2x \tan(11.25^\circ)$.

Gravitational settling is handled by tilting the plume downward after it has leveled off at height H by subtracting $V_g x/\mu$ from H in the plume dispersion equations. For CAP88-PC V_g is set at the default value of zero and cannot be changed by the user.

1.3 Dry Deposition

Dry deposition is modeled in the subroutine CONCEN as being proportional to the ground-level concentration of the radionuclide (Mo79):

$$R_d = V_d \chi$$

where:

$$\begin{aligned} R_d &= \text{surface deposition rate (pCi/cm}^2\text{-sec)} \\ V_d &= \text{deposition velocity (cm/sec) [VD]} \\ \chi &= \text{ground-level concentration (chi) in air (pCi/cm}^3\text{) [ACON]} \end{aligned}$$

Although V_d has units of velocity, it is only a proportionality constant and is usually higher than the actual, measured velocity of radionuclides falling to the ground. The proportionality constant must include deposition from fallout interception by foliage, which subsequently falls to the ground and so adds to ground deposition. Defaults for deposition velocity used by CAP88-PC are 3.5E-2 m/sec for iodine, 1.8E-3 m/sec for particulates and zero for gases.

1.4 Precipitation scavenging

The deposition rate from precipitation scavenging (Mo79), which occurs when rain or snow removes particles from the plume, is modeled in CONCEN with:

$$R_s = \phi \chi_{\text{ave}} L$$

where:

$$\begin{aligned} R_s &= \text{surface deposition rate (pCi/cm}^2\text{-sec)} \\ \phi &= \text{scavenging coefficient (sec}^{-1}\text{) [SC]} \\ \chi_{\text{ave}} &= \text{average concentration in plume up to lid height (pCi/cm}^3\text{) [ACON]} \\ L &= \text{lid height (tropospheric mixing layer) (cm) [LID]} \end{aligned}$$

The scavenging coefficient, ϕ (in sec^{-1}), is calculated in CAP88-PC by multiplying the rainfall rate, [RR] (in cm/yr), by 1E-7 yr/cm-sec.

1.5 Plume Depletion

Radionuclides are depleted from the plume by precipitation scavenging, dry deposition and radioactive decay. Depletion is accounted for by substituting a reduced release rate, Q^1 , for the original release rate Q for each downwind distance x (S168). The ratio of the reduced release rate to the original is the depletion fraction. The overall depletion fraction used in CAP88-PC is the product of the depletion fractions for precipitation scavenging, dry deposition and radioactive decay.

For precipitation scavenging the depletion fraction for each downwind distance (x) is:

$$\frac{Q^1}{Q} = e^{-\phi t}$$

where:

$$\begin{aligned} \phi &= \text{scavenging coefficient (sec}^{-1}\text{) [SC]} \\ t &= \text{time (sec) required for the plume to reach the downwind} \\ &\quad \text{distance } x \end{aligned}$$

The depletion fraction for dry deposition is derived by using Equation (6) with z set to zero for ground-level concentrations, and subtracting the quantity $(V_g x)/U$ from H for a tilted plume (Va68, Mo79):

$$\frac{Q^1}{Q} = \exp\left\{-\left(\frac{2}{\pi}\right)^{1/2} \frac{V_d}{\mu} \int_0^x \frac{\exp[-(H-V_g x/\mu)^2/2\sigma_z^2]}{\sigma_z} dx\right\}$$

where:

$$\begin{aligned} V_d &= \text{deposition velocity (m/sec) [VD]} \\ \mu &= \text{wind speed (m/sec) [U]} \\ \sigma_z &= \text{vertical dispersion coefficient (m)} \\ V_g &= \text{gravitational velocity (m/sec) [VG]} \\ H &= \text{effective stack height (m)} \\ x &= \text{downwind distance (m)} \end{aligned}$$

The integral expression must be evaluated numerically. Values for the vertical dispersion coefficient σ_z are expressed as functions of x in the form x^D/F where D and F are constants with different values for each Pasquill atmospheric stability category, to facilitate integrations over x .

Values for the depletion fraction for cases where V_g is zero are obtained from the subroutine QY in CAP-88. Subroutine QY obtains depletion fractions for the conditions $V_d = 0.01$ m/sec and

$\mu = 1$ m/sec for each Pasquill stability category from the data file REFA.DAT. This file contains values for release heights (meters) of:

1, 1.5, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12.5, 15, 17.5, 20, 25, 30, 35, 40, 50, 60, 70, 80, 90, 100, 120, 140, 160, 180, 200, 240, 260, 300 and 400.

and for downwind distances (meters) of

35, 65, 100, 150, 200, 300, 400, 500, 650, 800, 1,000, 1,500, 2,000, 4000, 7,000, 10,000, 25,000, 60,000, 90,000, and 200,000.

The stored depletion fractions were calculated numerically with a Simpson's rule routine. QY uses a linear interpolation to produce a fraction for the require downwind value, release height and Pasquill category for $V_d = 0.01$ m/sec and $\mu = 1$ m/sec. The value is then converted to the appropriate value for the actual deposition velocity and wind speed by use of the equation:

$$(Q^1/Q)_2 = (Q^1/Q)_1^{100 V_d/\mu}$$

in which subscript 2 refers to the desired value and subscript 1 refers to the value for $V_d = 0.01$ m/sec and $\mu = 1$ m/sec.

For downwind distances greater than $2x_L$ where Equation 15 applies to the ground-level concentrations in air, the depletion is modeled with (Mo79):

$$\frac{Q_x^1}{Q_{2x_L}^1} = \exp[-V_d(x - 2x_L)/L \mu]$$

which shows the reduced release rates at distances x and $2x_L$, respectively.

The depletion fraction for radioactive decay is:

$$\frac{Q^1}{Q} = e^{-\Lambda_r t}$$

where:

Λ_r = effective decay constant in plume [ANLAM]
 t = time required for plume travel

The decay constant used is referred to as the "effective decay constant" since it is not the true radiological decay constant in all cases. For example, if a radionuclide is a short-lived decay product in equilibrium with a longer-lived parent, the effective decay constant would be equal to the true radiological decay constant of the parent.

The atmospheric dispersion equations use the reciprocal-averaged wind speed, but neither this value nor the true average wind speed can adequately be used to calculate reduced release rates to account for radiological decay and scavenging losses because averaging of exponential terms is required. CAP88-PC uses an approximate calculational method for this purpose which establishes three wind speeds (1 m/sec, the average wind speed, and 6 m/sec) to simulate the actual wind-speed spectrum for each specific wind direction and Pasquill category. The wind speeds 1 and 6 m/sec were chosen because they approximate the upper and lower bounds in most meteorological data sets.

If f_1 , f_2 and f_3 are designated as the time fractions for the three wind speeds, then:

$$f_1 + (\mu_a f_2) + 6f_3 = \mu_a$$

$$f_1 + (f_2/\mu_a) + f_3/6 = 1/\mu_r$$

and

$$f_1 + f_2 + f_3 = 1$$

where:

$$\begin{aligned} \mu_a &= \text{Arithmetic-average wind speed [UDAV]} \\ \mu_r &= \text{Reciprocal-average wind speed [UDCAT]} \end{aligned}$$

Solving the three simultaneous equations yields:

$$f_1 = 1 - f_2 - f_3$$

$$f_2 = \frac{(7/6) - (\mu_a/6) - (1/\mu_r)}{(7/6) - (\mu_a/6) - (1/\mu_a)}$$

$$f_3 = \frac{(\mu_a - 1)(1 - f_2)}{5}$$

The depletion fraction to account for radioactive decay is then approximated by:

$$f_1 \exp(-\lambda_r x) + f_2 \exp[-\lambda_r(x/\mu_a)] + f_3 \exp[-\lambda_r(x/6)]$$

where:

$$\begin{aligned} \lambda_r &= \text{effective decay constant in plume (sec}^{-1}\text{) [ANLAM]} \\ \mu_a &= \text{Arithmetic-average wind speed [UDAV]} \\ x &= \text{downwind distance (m)} \end{aligned}$$

For precipitation scavenging losses, the depletion fraction is:

$$f_1 \exp(-\phi x) + f_2 \exp[-\phi(x/\mu_a)] + f_3 \exp[-\phi(x/6)]$$

where ϕ is the scavenging coefficient (sec^{-1}).

The overall depletion fraction is calculated by multiplying the depletion fraction for dry deposition by the fraction for radioactive decay and precipitation scavenging.

1.6 Dispersion Coefficients

Horizontal and vertical dispersion coefficients (σ_y and σ_z) used for dispersion calculation in CONCEN and for depletion fraction determination in QY are taken from recommendations by G.A. Briggs of the Atmospheric Turbulence and Diffusion Laboratory at Oak Ridge, Tennessee (Mo79, Gi76). The coefficients are different functions of the downwind distance x for each Pasquill stability category for open-country conditions, as shown:

<u>Pasquill category</u>	σ_y <u>(m)</u>	σ_z <u>(m)</u>
A	$0.22 x (1 + 0.0001x)^{-1/2}$	$0.20 x$
B	$0.16 x (1 + 0.0001x)^{-1/2}$	$0.12 x$
C	$0.11 x (1 + 0.0001x)^{-1/2}$	$0.08 x (1 + 0.0002x)^{-1/2}$
D	$0.08 x (1 + 0.0001x)^{-1/2}$	$0.06 x (1 + 0.0015x)^{-1/2}$
E	$0.06 x (1 + 0.0001x)^{-1/2}$	$0.03 x (1 + 0.0003x)^{-1}$
F	$0.04 x (1 + 0.0001x)^{-1/2}$	$0.016 x (1 + 0.0003x)^{-1}$
G	calculated by subtracting half the difference between values for categories E and F from the value for category F.	

where:

x = downwind distance

CAP88-PC uses the functions in the form of

$$\begin{aligned} \sigma_y &= x^A / C \\ \sigma_z &= x^D / F \end{aligned}$$

to facilitate integrations over x. Values for A,C, D, and F for each stability category and downwind distance are stored in a data statement.

1.7 Area Sources

Uniform area sources are modeled in CAP88-PC using a method described by Mills and Reeves, as modified by Christopher Nelson, EPA, and implemented by Culkowski and Patterson (Mo79). The method transforms the original area source into an annular segment with the same area. The transformation is dependent on the distance between the centroid of the area source and the receptor. At large distances (where the distance/diameter ratio is 2.5), the area source is modeled as a point source; at close distances it becomes a circular source centered at the receptor. A point source model is also used if the area source is 10 meters in diameter or less.

The principle of reciprocity is used to calculate the effective chi/Q. The problem is equivalent to interchanging source and receptor and calculating the mean chi/Q from a point source to one or more sector segments according to the angular width of the transformed source. The mean value of chi/Q for each sector segment is estimated by calculating chi/Q at the distance which would provide the exact value of the mean if the variation in chi/Q were proportional to $r^{-1.5}$ for distances from the point source to location within the sector segment. The chi/Q for the entire transformed source is the sum of the chi/Q values for each sector weighted by the portion of the total annular source contained in that sector.

1.8 Carbon-14 and Tritium

Special consideration is given to the radionuclides hydrogen-3 (tritium), carbon-14, and radon-222. The specific activity of tritium in air is calculated for an absolute humidity of 8 mg/m³. The specific activity of atmospheric carbon-14 is calculated for a carbon dioxide concentration of 330 ppm by volume. Concentrations of these nuclides in vegetation are calculated on the assumption that the water and carbon content in vegetation are from the atmosphere and have the same specific activity as in the atmosphere. Drinking water is assumed to be one percent (1%) tritiated.

1.9 Rn-222 Working Levels

The radon decay product concentration (in working level units) is estimated using an equilibrium fraction that varies as a function of travel time, assuming a wind speed of 3.5 meters/second, with a final equilibrium fraction of 0.7.

Equilibrium fractions for radon decay products are calculated as a function of downwind distance, starting at 0.267 at 150 meters and reaching a final equilibrium fraction of 0.698 at 19,551 meters. Equilibrium fractions for specific distances are calculated by linear interpolation, using this table:

<u>Distance (meters)</u>	<u>Equilibrium Fraction</u>
150	.267
200	.273
250	.276
300	.278
400	.284
500	.289
600	.293
800	.302
1000	.311
1500	.331
2000	.349
2500	.366
3000	.382
4000	.414
5000	.443
6000	.471
8000	.522
10000	.566
15000	.650
19551	.698

1.10 Ground Surface Concentrations

Ground surface and soil concentrations are calculated for those nuclides subject to deposition due to dry deposition and precipitation scavenging. The deposition accumulation time, [TSUBB], is assumed to be 100 years. This value corresponds to establishing a 100-year cutoff for the time following a release when any significant intake or external exposure associated with deposition on soil might take place.

Ingrowth from a parent radionuclide is calculated using a decay product ingrowth factor. The ingrowth factor is the ratio of the decay product concentration resulting from a unit deposition rate of the parent and the decay product respectively. The factors are for a 100 year accumulation time and a removal rate from soil of 2 percent per year.

2. DOSE AND RISK ESTIMATES

CAP88-PC uses a modified version of DARTAB (ORNL5692) and a database of dose and risk factors generated by RADRISK (ORNL7105, ORNL7745) for estimating dose and risk. Relevant portions of these documents are reproduced here, as referenced.

Dose and risk conversion factors include the effective dose equivalent calculated with the weighting factors in ICRP Publication Number 26 (ICRP26). Risk factors are based on lifetime risk from lifetime exposure with a nominal value of 4E-4 fatal cancers/rem (EPA89). Dose and risk factors are provided for the pathways of ingestion and inhalation intake, ground level air immersion and ground surface irradiation. Factors are further broken down by particle size [SIZE], clearance class [CLEARANCE_CLASS] and gut-to-blood [GI_ING and GI_INH] transfer factors. These factors are stored in a database for use by the program.

For assessments where Rn-222 decay products are not considered, estimates of dose and risk are made by combining the inhalation and ingestion intake rates, air and ground surface concentrations with the appropriate dose and risk conversion factors. CAP88-PC lists the dose and risk to the maximum individual and the collective population. CAP88-PC calculates dose to the gonads, breast, red marrow, lungs, thyroid, and endosteum in addition to the 50 year effective dose equivalent. Risks are estimated for these cancers: leukemia, bone, thyroid, breast, lung, lung, stomach, bowel, liver, pancreas and urinary. Doses and risks can be further tabulated as a function of radionuclide, pathway, location and organ.

For assessments of Rn-222 decay products, CAP88-PC calculates working levels, not concentrations of specific radionuclides. A working level [WLEVEL] is defined as any combination of short-lived radon decay products in 1 liter of air that will result in the ultimate emission of 1.3×10^5 MeV of alpha particle energy. CAP88-PC calculates risk, but not dose, from the working level calculations. Risk to the maximum individual and the collective population are tabulated.

For each assessment, CAP88-PC tabulates the frequency distribution of risk, that is, the number of people at various levels of risk (lifetime risk). The risk categories are divided into powers of ten, from 1 in ten to one in a million. The number of health effects are also tabulated for each risk category.

2.1 Air Immersion

Individual dose is calculated for air immersion with the general equation:

$$\frac{E_{ij}(k) DF_{ij} K_j}{P(k)}$$

where:

$$\begin{aligned}
 E_{ij}(k) &= \text{exposure rate, person-pCi/cm}^3 \text{ [EXPP]} \\
 DF_{ijl} &= \text{Dose rate factor, mrem/nCi-yr/m}^3 \text{ [DOSE]} \\
 P(k) &= \text{number of exposed people [POP]} \\
 K_j &= 0.001 \text{ nCi/pCi} \times 1,000,000 \text{ cm}^3/\text{m}^3 \text{ (proportionality} \\
 &\quad \text{factor) [FAC]}
 \end{aligned}$$

Risk is calculated similarly, by substituting the risk conversion factor, RISK, for DOSE. The risk conversion factor is in units of risk/nCi-yr/m³.

2.2 Surface Exposure

Individual dose is calculated for ground surface exposure with the general equation.

$$\frac{E_{ij}(k) DF_{ijl}}{P(k)} K_j$$

where:

$$\begin{aligned}
 E_{ij}(k) &= \text{exposure rate, person-pCi/cm}^2 \text{ [EXPP]} \\
 DF_{ijl} &= \text{Dose rate factor, mrem/nCi-yr/m}^2 \text{ [DOSE]} \\
 P(k) &= \text{number of exposed people [POP]} \\
 K_j &= 0.001 \text{ nCi/pCi} \times 10,000 \text{ cm}^2 / \text{m}^2 \text{ (proportionality factor)} \\
 &\quad \text{[FAC]}
 \end{aligned}$$

Risk is calculated by substituting the risk conversion factor, RF_{ijl} [RISK], for DF_{ijl} [DOSE]. The risk conversion factor is in units of risk/nCi-yr/m².

2.3 Ingestion and Inhalation

Individual dose is calculated for the ingestion and inhalation exposure pathway with the general equation:

$$\frac{E_{ij}(k) DF_{ijl}}{P(k)} K_j$$

where:

$$\begin{aligned}
 E_{ij}(k) &= \text{exposure rate, person-pCi/cm}^3 \text{ [EXPP]} \\
 DF_{ijl} &= \text{Dose rate factor, mrem/nCi-yr/m}^3 \text{ [DOSE]} \\
 P(k) &= \text{number of exposed people [POP]} \\
 k_j &= 0.001 \text{ nCi/pCi} \times 1,000,000 \text{ cm}^3 / \text{m}^3 \text{ (proportionality} \\
 &\quad \text{factor) [FAC]}
 \end{aligned}$$

Risk is calculated by substituting the risk conversion factor, RISK (risk/nCi), for DOSE.

2.4 Maximally-Exposed Individual

Doses for the maximally-exposed individual in population runs are estimated by CAP88-PC for the location, or sector-segment in the radial assessment grid, of highest risk where at least one individual actually resides. The effective dose equivalent for the maximally-exposed individual is tabulated in mrem/yr for a 50 year exposure. Risk is estimated as total lifetime risk for a lifetime exposure [AGEX] of 70.7565 years.

2.5 Collective Population

Collective population dose and risk are found by summing, for all sector segments, the intake and exposure rates multiplied by the appropriate dose or risk conversion factors (ORNL5692). Collective population dose is reported by person-Rem/yr (not millirem), and collective risk is reported in deaths/yr. Note that collective risk is reported as annual risk, while maximally-exposed individual risk is reported as lifetime risk.

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